COMMENT DRAFT

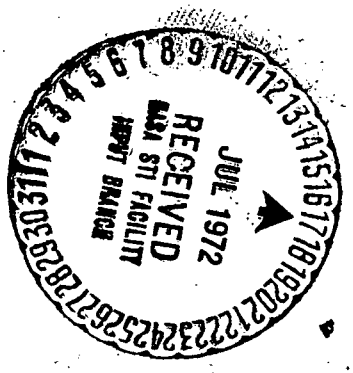
X-68502-01

AERIAL ARCHAEOLOGY IN THE SPACE AGE

(HHN-107)

by

Mary Marguerite Scalera



NASA Historical Division
Office of Policy
National Aeronautics and Space Administration
Washington, D.C.
August, 1970

PREFACE

When I accepted a summer job with the NASA Historical Division, I had no idea that my duties would be transformed from the established routine of a clerk-typist to the challenging prospect of writing a research paper. This pleasant surprise also presented a terrible dilemma, i.e., choosing a topic. There were so many fascinating possibilities. I was in a quandary trying to decide on one of several suggested topics, until I read "Ecological Surveys from Space" (NASA SP-230). This brief overview of the vast potential and uses of remote sensing from spacecraft was remarkable. I became interested in doing a topic related to earth resources.

Then the problem became one of limiting my topic. In one of our seminar meetings, Dr. Emme, NASA Historian, mentioned that he recalled reading of archaeological sites revealed by remote sensing from space photography and suggested that I look into this. From this suggestion and weeks of research at the Library of Congress, there developed the idea of "aerial archaeology in the space age." This was the perfect topic, in my opinion, because it not only dealt with remote sensing techniques, but also was a clearly defined topic, whereas earth resources had been too broad.

I found the development of aerial archaeology fascinating and also felt that it provided a necessary background and frame of reference for the space age developments in aerial archaeology. The history of aerial

archaeology falls into three periods, so I have divided my paper in like manner. During the first period, before World War I, aerial photography was conceived of as valuable in the recording of known monuments. During the years between World War I and II a few pioneers worked with verticle and oblique photographs which revealed new sites by means of crop, soil and shadow marks. In the period following World War II stereoscopic examination came into extended use,and total vertical coverage of large areas was made. In the last decade, the space age, modern technology has vastly increased the capabilities of aerial archaeology.

In this paper I have tried to briefly give the history of aerial archaeology, emphasizing the last decade and its technological advances. Unfortunately much more has been written about aerial archaeology before World War II, making a chronological account of events the most appropriate approach. However, the events since World War II did not fit this pattern easily. I hope this is not sorely obvious to the reader. There were some problems with documentation, ranging from conflicting reports of the same events to lack of documentation on recent undertakings. Also, many of the recent reports were of too technical a nature for my purpose. Time was another limiting factor, making it difficult to use some prime sources of documentation, for example archaeologists who will not return from distant field work until the fall.

However, I was able to get in touch with many people here in the

States, and their quick response was most helpful. I would especially like to thank Mr. Frank Goodson of the Research Data Facility at NASA's Manned Spacecraft Center, Dr. Thomas R. Lyons, Assistant Director of the Technology Applications Center at the University of New Mexico, and Mr. Gary North, Remote Sensing Specialist, Geographic Applications Program, U.S. Geological Survey, for the time they spent in helping me get this paper underway. I hope this comment draft is worthy of their efforts.

TABLE OF CONTENTS

	pages
INTRODUCTION	iv-ix
PRIOR TO WORLD WAR I	1-3
The First Aerial Photograph	1
Early British Pioneers	2-3
WORLD WAR I THROUGH WORLD WAR II	4-13
Improvements in the airplane and the camera	4-5
Contributions during World War I	5-7
Dr. O. G. S. Crawford	7
Oblique PHotographs and Shadow Marks	7-8
Vertical Photographs and Soil and Crop Marks	8-9
Aerial Archaeology in the United States	10-11
Improvements During World War II	11-12
Stereoscopic Photographs	12-13
AFTER WORLD WAR II	14-25
The first Decade after World War II	14-15
Space Age improvements in Aerial Archaeology	17-20
Aerial Archaeology from Spacecraft	20-24
Gemini IV	21-22
Nimbus I	23
Apollo 9	23-24
Utilization of spacecraft Equipment	24
Aerial Archaeology from NASA aircraft	24-25
CONCLUSIONS	26-27

INTRODUCTION

Curious to know more about himself, man has always been interested in uncovering and preserving his past. More than one discipline has been developed for this purpose. Anthropology deals with man's physical character, historical and present geographical distributions, racial classification, and group relationships. History and archaeology deal with the study of man's social and cultural development. The two disciplines have essentially the same aim, differing mainly in the techniques they employ. History is mainly concerned with the written record from classical times to the present, revealing the interactions of peoples and events. On the other hand, archaeology concerns itself with the long period from the emergence of mankind to the start of literate civilizations in the Greek and Roman world and includes every concrete manifestation of human activities in its study. Both history and archaeology have benefited greatly from the use of aerial photography.[1] This paper deals only with aerial archaeology, the use of aerial photography and other remote sensing techniques in archaeology.

Archaeology includes the discovery and examination of all traces of human activities in past ages, principally fortifications, habitations, and agriculture. The earliest periods of archaeology are known mainly in terms of implements and artifacts, for no man-made constructions

---

[1] J. K. S. St. Joseph, (ed.), The Uses of Air Photography, John Baker Pub., Ltd., London, 1966, p. 26.

ordinarily survive, certainly none visible from the air. However, from the Neolithic period onwards man has left ever-increasing traces of his existence. In archaeology one aim is to discover these evidences of man's past existence. Until the advent of aerial photography, discovery of buried sites was largely by chance as when an occasional find revealed the position of an ancient settlement. Today the process of discovery is transformed, since aerial reconnaissance in competent hands can yield discoveries at a rate previously undreamed of. No other means than aerial archaeology exist for assessing the archaeological potential of an area where there are no visible remains.[2]

Excavation is no longer everything to the archaeologist. Archaeologists no longer search for beautiful isolated objects but for cultural units and defunct societies. The archaeologist wants to recapture a way of life. As Deuel says, "No other technical advance has come so close to fulfilling the goal of recovering intricate cultural contexts of glimpsing whole prehistoric landscapes and of capturing a fabric of human existence through the flux of time. Observation from the air is unique, distance rather than proximity can be a boom for students of buried yesterdays."[3] The aerial camera can range effectively not only in space but in time, also. Aerial photographs can record the life of a

---

[2] Leo Deuel, Flights into Yesterday, The Story of Aerial Archaeology, St. Martin's, New York, 1969, p. 28.

[3] Ibid., p. 7.

primitive people still living today, their types of settlement, their fortifications, agricultural practices, cattle enclosures and even burial grounds. This type of information is of great value to archaeology as an illustration to be used in interpreting the past.[4] From the air one can often see new relationships between the past and the present.

It may seem strange that one can see from the air what is undiscernible on the ground. It must be remembered that human seeing is not a mere passive acceptance of reflected light, but an active organization of the retinal field of vision into intelligible forms. Significant patterns spread out upon the surface of the earth can not be seen as a whole from piecemeal inspection at a close distance. However, at a sufficient distance, as from an aerial view one can identify a whole pattern or shape.[5]

Aerially disclosed ground patterns are fortuitous and incoherent when they are the product of purely natural conditions of geological formation or vegetable growth without human intrusion. A fully articulated pattern displaying geometric symmetry and repetitious order almost always gives evidence of human activity for its creator. Uninhabited and uncultivated land is characteristically devoid of the particular types of patterns that man introduces whenever he plants

---

4 W. F. Grimes, (ed.), Aspects of Archaeology in Britain and Beyond, H. W. Edward Pub., London, 1951, p.312.

5 James S. Ackerman and Rhys Carpenter, Art and Archaeology, Prentice-Hall, Inc., New Jersey, 1963, p. 22.

crops or builds roads, towns, cemeteries, etc. Long after these constructions have fallen into disuse, and passed into ruin to become concealed under accumulated refuse or dust or rain-washed soil, their buried outlines continue to affect the vegetation rooted upon them whether this be chance natural growth or planted fields.[6]

Since any more or less geometric arrangement almost invariably betrays a human builder the airborne archaeologist has relatively little difficulty in identifying artificial structure, no matter how much its substance has been reduced.[7] Aerial archaeology's greatest triumph is that it has become an independent instrument of discovery which can detect features never noticed before and fix them on film, " a blueprint of long vanished civilizations."[8]

Though the discovery of new sites may be the most exciting area, it is not the only area of archaeology in which aerial photography is put to good use. It is not often that entirely new sites are discovered. According to Reeves the principle use of aerial photography should be to complete data on known sites. In areas known to contain archaeological sites it saves time and money to take aerial surveys, recording this information.[9] A peculiar value of aerial photographs is that they can display the character of ancient earthworks far more effectively than any plans yet available. They are also excellent material for teaching and a most powerful research weapon. Where earthworks of different ages

---

[7] Deuel, p. 8.

[8] Ibid., p. 9.

[9] Dache M. Reeves, "Aerial Photography and Archaeology", American Antiquity, Vol. 2, p. 105.

are superimposed, aerial photographs may be able not only to demonstrate the existance of distinct systems, but also to establish their relative ages.[10]

Before digging a series of aerial photographs should be made, depicting the area under various climatic conditions. Changes of soil under different climatic conditions will bring out a sharper more complete picture of what is to be found beneath the soil. This in undoubtably cheaper than the usual blind digging. Aerial photography reduces the amount of time needed to make the contour survey of a site.[11] Moreover, aerial photographs reveal the landscape in minute detail and in three dimensional relief (stereoscopic photographs) when viewed in the proper manner,and they can be studied before the party enters the field of operations. Aerial photography is also particularly effective in keeping a record of the various phases of operation once a dig is underway. A series of photographs can be taken showing the progress of the work. Each successive stratum may be recorded quickly by aerial photography.[12]

Aerial photographs also save time and money by being a guide to avoid the problem of carrying excavation beyond the necessary limits or not far enough so that an important part of a site may be missed entirely.[13]

---

[10] Grimes, pp. 306 & 307.

[11] Henry A. Detweiler, Manual of Archaeological Surveying, American Schools of Oriental Research, New Haven, 1948, p. 35.

[12] Reeves, p. 106.

[13] Ibid., p. 105.

Aerial mapping can telescope years of work on foot into a span of weeks.[14] Without expertise surveyors, the photographic product is still likely to be superior to maps made by experts on the ground. The photograph registers minute and frequently elusive and transient details and is of course up to date. It is possible on suitable photographs to locate features within thirty feet or less of their true geographical position, permitting the recording of archaeological sites and key points along obscure routes with an accuracy impossible on most field or topographic maps. The site identification number and other identifications are noted on the back of the prints beside pin hole marking which indicate the exact location of the points of interest. This makes a permanent record which does not deface the pictures.[15]

Many of the above uses of aerial photographs require that they be taken from low altitudes, even from tethered balloons. However, in the discovery of new sites and important geomorphological features in general, aerial archaeology has been greatly influenced by modern technology and photographs are now taken, not only from aircraft, but also from spacecraft. Moreover, in the space age, aerial archaeology has become a sophisticated technical field, utlizing many means of remote sensing in addition to ordinary photography. To truly appreciate these modern techniques, one must study the development of aerial archaeology starting with its simple beginnings.

---

[14] John Bradford, Ancient Landscapes: Studies in Field Archaeology, G. Bell and Sons, Ltd., London, 1957, p. 4.

[15] William C. Miller, "Uses of Aerial Photographs in Archaeological Field Work", American Antiquity, Vol. 23, No. 1, p. 46.

PRIOR TO WORLD WAR I

Aerial archaeology presupposes two major inventions: the airplane and the photograph. The history of aerial archaeology is closely tied to the development of these inventions. Moreover, because the development of flight and photography has often been through military purposes, the history of aerial archaeology is also linked to military history.

Long before the airplane was invented, archaeologists confidently hoped that vertical photographs would some day be taken. Dr. Williams-Freeman used to tell the young and promising, O. G. S. Crawford, "One ought to be a bird in order to be a field archaeologist."[16] Taking photographs from the air was actually first suggested as a joke in a French lithographed caricature published in the middle of the nineteenth century.[17] However, less than twenty years after the invention of the daguerrotype (one of the first methods of photography) the first aerial photograph was taken. The scene was Paris in October 1958 and the photographer was Gaspard Felix Tournachon (Nadar), an enthusiastic balloonist.[18] Shortly afterward aerial photographs were taken of Boston and London by other enthusiasts. Nadar was urged to use aerial photography for military purposes during the Franco-Italian War in 1859, but

---

16 Glyn E. Daniel, A Hundred Years of Archaeology, Gerald Duckworth and Co., Ltd. London, 1950, p.298.

17 Ibid., p. 294.

18 Deuel, p. 12.

he declined and the first military use of aerial photography was made in the American Civil War.[19]

Major Elsdale in the British Army was a pioneer of aerial photography. Between 1880 and 1887 he carried out many experiments from free floating balloons and invented a method of sending up small balloons just large enough to carry a camera. These cameras were self-releasing and designed to expose several plates successively. However, ballooning was not much in favour in the 1880's and these balloon photography experiments received little or no official support.[20]

In 1891 another British Army officer, Lt. C. F. Close tried to use a similar device to photograph extensive ruins near Agra, India in order to produce an archaeological map of the area. Unfortunately his project did not get under way, frustrated by lots of red tape. Meanwhile the military history of aerial archaeology entered a new phase in England.

In 1906, more or less by accident, Lt. P. H. Sharpe took the first aerial photograph of an archaeological site, an oblique and vertical photograph of Stonehenge.[21] These photographs were taken from a British war balloon, and though they revealed remains not visible on the ground, the great potential of aerial photography for discovery was not realized at that time.[22]

---

19 Daniel, p. 294.

20 O. G. S. Crawford and Keiller, Wessex From the Air, Oxford Univ. Press, London, 1928, p. 3.

21 Deuel, p. 14.

22 Daniel, p. 294.

Balloons were not the only method tried in getting the camera aloft. In 1913 Mr. Henry S. Wellcome successfully used large boxkites with specially devised automatic control cameras for photographing his archaeological sites and excavations in the Upper Nile regions of the Anglo-Egyptian Sudan. Mr. Wellcome and other archaeologists were convinced of the worth of aerial photographs, but it was extremely difficult to get the camera aloft.[23]

In addition to the difficulty of getting the camera in the air, a second major obstacle was the camera itself. The quality of the lens and the panchromatic plates or films needed improvement. However, archaeologists at the time felt that if sufficient demand developed, manufacturers would provided a high-grade small aerial camera suitable for aerial archaeology.[24] World War I was the necessary military stimulus for the improvement of the camera and the means of getting it aloft.

---

[23] Reeves, p. 102.

[24] Ibid., p. 106.

WORLD WAR I THROUGH WORLD WAR II

The airplane came of age in World War I and from then on major advances in aerial archaeology were linked with heavier-than-air aviation. Dr. Williams-Freeman's wish that archaeologists could become birds came true and men like Crawford and others got a bird's-eye view of the countryside,[25] observing the patterns of the past and photographing them. The war not only improved flying techniques of reconnaissance, but also photoequipment, lenses, plates and films. Brig. General George W. Goddard invented the strip camera which has no shutter but exposes film by passing it steadily across an extremely narrow slit. The strip camera gives clear pictures at any altitude and at any speed. Used with controlled overlapping of film exposure, it produces a stereoscopic effect so that the tilt of a beach, the depth of water and the tide extremes can be determined[26] and even the size of objects measured within an inch.

The new techniques of reconnaissance called for specially trained personnel and archaeologists, especially in Britain, were enlisted in the Flying Corps and were active as photographers, mapmakers, and observers. Concerning this tie between archaeology and war, Deuel writes, "An odd, if not ironic, symbiosis seems to exist between war and archaeology. Perhaps experts in dolmens, ditches and derelic structures of the past were judged

---

[25] Glyn E. Daniel, Man Discovers His Past, Thomas Y. Crowell Co., 1968, p. 76.

[26] Michael Kernan, "An 'Overview' of Aerial Photography", Washington Post, March 30, 1970.

well suited to lend a helping hand in producing similar fragments for the Runienschmerz of generations still to come."[27]

World War I did not bring about many new discoveries from aerial archaeology. Applications of aerial photographs were limited almost entirely to military uses, including mapping. The rapid improvement in methods of photographic mapping resulted in the formation of the new science of photogrammetry. But progress in archaeological use of aerial photographs was slow, partly due to the expense but mostly due to lack of familiarity with aerial photographs on the part of many archaeologists. Comparatively few photographs were taken for specifically archaeological purposes,and aerial photographs were considered as valuable aids for recording known monuments but not a new means of discovery of new sites.[28]

However, the archaeological value of aerial photograph was recognized by some British, French and German scholars working on military photographic duties during the war.[29] Clear cut priority as to who was first on this aerial archaeological scene has not yet been established.

As early as 1915, the French archaeologist, Leon Rey, examined aerial photographs of ancient sites in Macedonia. Another Frenchman, Jerome Carcopino urged the commander of French expeditionary forces at Dardonelles to let his squadron take pictures of near-by Troy.[30] Father Antoine Poidebard from the staff of the University of Beruit studied aerial photographs of

---

[27] Deuel, p. 15.

[28] Reeves, p. 103.

[29] Daniel, A Hundred Years of Archaeology, p. 296

[30] Deuel, p. 15.

the Near East with the cooperation of the French Air Force. Later, after the war, he was able to map defense lines (the limes) that the Romans had established across the Syrian Desert. He also surveyed the ancient Phoenician city of Tyre.[31]

Most historians agree that the Germans were first to undertake an aerial mission specifically for archaeological purposes, and give major credit for pioneer work during World War I to them. When the German forces were operating in Sinai and southern Palestine, a special Commission for the protection of historical monuments in the Near East was set up under Dr. Theodore Wiegard. Its specific purpose was to photograph ancient sites.[32] Some of the results were published in 1920.

Lt. Colonel G. A. Beazeley, a professional British soldier, during his repeated flights over the Tigris-Euphrates sighted sharp outlines of ancient canals and towns laid out geometrically. He photographed many ancient town sites and irrigation channels in Mesopotamia, and in 1919 he published a brief account of his discoveries. In that same year, Dr. O. G. S. Crawford discovered a missing portion of Stonehenge from a war photograph. Due to Crawford's influence all aerial photographs of archaeological interest taken during the war were transferred to the Ordance Survey Office and he was appointed Archaeological Officer to that office.[33] Beazeley and Crawford were the first to realize the true

---

[31] Henri-Paul Eydoux, History of Archaeological Discoveries, Leisure Arts, Ltd., Switzerland, 1966, p. 96.

[32] Wheeler, "New Techniques", S. Rapport & H. Wright (ed.), New York University Press, 1963, p. 55.

[33] Crawford, Wessex From the Air, p. 5.

significance of aerial photographs to archaeology. They realized that the same skill used to scrutinize the earth's surface for signs of enemy activity could be used to interpret natural and artificial features of the landscape and discover new archaeological sites.[34]

During the early 1920's, Crawford who was one of the major exponents of aerial archaeology in the period between World War I and World War II, did a great deal of work. He was the leader of a new study in England that came about in 1922 when Air Commodore Clark Hall noticed some curious marks on RAF aerial photographs. Crawford and Dr. Williams-Freeman examined these photographs with Hall and found that it was possible to make maps of the Celtic field system.[35] Under Crawford's leadership, whole field systems dating roughly from 500 BC to 500 AD were identified in England, revolutionizing our knowledge of ancient agriculture.[36]

In the years after World War I, Beazeley, Crawford, Allen and Poidebard utilized vertical and oblique aerial photographs taken with hand held cameras. From these photographs, shadow, soil, and crop marks, which revealed information of value in discovering new sites, were obtained.[37]

Oblique photographs reveal shadow marks. With the sun low, earthworks which appear to the ground observer as a confused tangle cast shadows out

---

34 St. Joseph, The Uses of Air Photography, p. 113.

35 Clarence Winchester and F. L. Willis, Aerial Photography, A Comprehensive Survey of its Practice and Development, Chapman & Hall,Ltd., 1928, p. 170.

36 Wheeler, p. 56.

37 Daniel, A Hundred Years of Archaeology, p. 300.

of all proportion to their size and the systems become clear.[38] Oblique sunlight can emphasize small differences in relief. Oblique photographs are taken when the sun is low in the sky and thus they can record long shadows present at that time of day, early morning or afternoon. Such photographs, taken when the sun is at an oblique angle to the area to be photographed and at right angles with the camera, show the existence for example of small strips of earth, such as those which divided the Celtic fields,[39] by the exaggerated shadows which are recorded on film.

Vertical photographs are used to record soil and crop marks. In vertical photographs the camera is in a verticle position, the lens axis perpendicular to the ground. Features on vertical photographs can be fairly easily transferred toa conventional map. Actually, a vertical photoraph is a map in itself, the scale being a function of the plane's altitude and the camera's focal length.[40] In such photographs the earth seems transparent and the marks of ancient civilizations show through.[41]

Soil marks are caused by contrasting lines of different kinds of earth. Where soil has been turned over in construction of earthworks there is a contrast between the soil and the subsoil. There are also contrasts between ditch filings and normal soil, between ground that has

---

[38] St. Joseph, "Air Photography and Archaeology", Geographical Journal, Vol. CV, Jan.-June 1945, p 54.

[39] Harold C. Simmons, Archaeological Photography, New York University Press, 1969, p. 71.

[40] Deuel, p. 10.

[41] Darsie Gillie, "Location of Archaeological Sites by Air, The Explorers Journal, Vol., 34, No. 2,3,4, 1956, p. 15.

been cleared of topsoil or stones and uncleared ground.[42] Once the subsoil has been disturbed it can never be replaced exactly as it was before.[43] Crawford noted that broad white bands seen from the air indicated lynchets beneath newer and larger field systems, such lynchets being formed of lighter soil. They came into existence when the area of ground was ploughed for a long time; the soil crept downhill to the boundaries of the field and unable to cross grass strips or unploughed earth dividing the fields, the soil eventually formed a bank or lynchet. This soil remained lighter and revealed itself centuries later on aerial photographs.[44]

Crop marks show up the conditions directly beneath ground level. Crops above areas where man has dug deeply and left pits, hollows, and trenches to become filled with silt and humus or where he has built wooden buildings which will decay, will grow taller, denser and brighter. Crops above walls, or stone foundations, where there is relatively little soil and penetrability, will be stunted in growth. From the air these differences in growth reveal patterns of past civilizations. The most striking results are obtained in a dry season, and when the vegetation is a long rooted cereal like wheat.[45] Grimes states that for a short period each year before harvest,"arable land appears like a parchment covered with hieroglyphs."[46]

---

[42] Shirley Gorenstein, Introduction to Archaeology, Basic Books, Inc. New York, 1965, p43.

[43] Leonard Cottrell, (ed.), The Concise Encyclopedia of Archaeology, Hawthorne Books, Inc. New York, 1960, p. 71.

[44] Winchester and Willis, p. 175.

[45] St. Joseph, The Uses of Air Photography, p. 116.

[46] Grimes, p. 313

In Britain such methods of interpreting aerial photographs increased the knowledge of their past as far back as two thousand years before the written record.[47] In the 1920's the United States also became involved in aerial photography. In 1921 one of the first aerial views of a prehistoric earthwork was taken of the Cahokia Mountain in Madison County Illinois from an Army flier.[48] Nine years later, Army fliers took photographs of an area in the Gila and Salt River Valleys in central Arizona for use in the study of prehistoric canals for the Smithsonian Institute.[49]

Beginning in 1933 and until the second world war, Dache M. Reeves then with the United States Army, took photographs of many earthwork sites in the Ohio Valley. This invaluable set of documents on American prehistory was left to the National Museum. During the same period Lt. George R. Johnson, working with the Peruvian Naval Service, included many views of archaeological sites in his aerial photography of Peru. Subsequently the Shippee-Johnson Peruvian Expedition that was only planning to record the most important ancient sites of Peru by oblique and vertical photographs and maps, discovered the "Great Wall of Peru," a pre-Inca construction near Chimbote. Many new sites were discovered by aerial expeditions of museums and educational institutions. Col. Charles A. Lindbergh was the leader of one of the first of these ventures. On a more modest scale, sites in the United States were also photographed from light planes

---

[47] Gillie, p. 15?.

[48] Reeves, p. 103.

[49] Manual of Photographic Interpretation, American Society of Photogrammetry, Washington, D.C., 1960, p. 719.

with hand-held cameras. The Smithsonian Institution took photographs of archaeological sites in the Missouri Basin also. Many other sites were discovered by interpretaion of aerial photographs taken for Soil Conservation purposes and from photographs taken for other government agencies.[50]

In Britain in the 1930's, Major G. Allen, using his own aircraft, took thousands of photographs in a few seasons. Also carrying on Crawford's work, Father Poidebard worked in Syria while ERic Schmidt was working in Iran. Their contributions have added much to the general knowledge of the topography and ancient routes of these areas.[51] In 1934 Poidebard published three works all of remarkable distinction.

World War II saw a tremendous increase in aerial photography due to: improvements in aerial cameras and airplanes, the great number of aircraft and cameras available, and the increased importance of photographic intelligence. The war provided hundreds of thousands of photographs from Norway to China, containing a vast mass of unrecorded archaeological data. Many archaeologists were employed as photographers and intelligence officers.[52]

Most notable is the work of J. S. P. Bradford on aerial photographs of Italy. Based on his studies plans for systematic programs of archaeological aerial surveys with the cooperation of Rome and Florence authorities developed.[53] Bradford also discovered in northern France cropsites on aerial

---

50 Manual of Photographic Interpretation, p. 719.

51 Henry A. Detweiler, Manual of Archaeological Surveying, American Schools of Oriental Research, New Haven, 1948, p. 35.

52 Daniel, A Hundred Years of ARchaeology, p. 299.

53 Bradford, p. 5.

photographs from World War II.[54] Military aerial photographs taken at the time of Allied beachhead landings near Paestrum in southern Italy (1943-45) brought out the grid of streets and their adjoining block of houses for almost the entire city of the Roman period though these had previously been completely unapparent.[55]

World War II not only increased the range of aerial photography and the number of photographed areas but also increased the intensity of photographic coverage. Before 1939 hardly any attempt at total photographic coverage was made, but during the war it became a matter of total coverage and archaeologists of western Europe now have available complete aerial maps of cultural and natural landscapes of the areas they are studying. Aerial archaeology is now an essential part of archaeological techniques. The work of military photographic interpretation during the war taught prehistorians the value of stereoscopic examination of aerial photographs.

Stereoscopic photographs are made with a large overlap in both directions. The effect is that the relief of barely noticeable elements is exaggerated because the two viewpoints corresponding to the human eyes are moved a greater distance apart by using the overlapping photographs. This lessens the natural foreshortening of the vertical surface. The

---

[54] R. Agache, "Aerial REconnaissance in Picardy," Antiquity, Vol. 28, 1954, p. 113.

[55] Ackerman, and Carpenter, p. 24.

effect of exaggerated definition can be advantageous in archaeology. This effect is very helpful in ordinary aerial reconnaissance work where every slight relief may be an important clue to what exists beneath the surface.[56]

Since World War II, Dr. J. K. S. St. Joseph of Cambridge University has cooperated skillfully with the RAF in systematic photography of this kind and his results, stored at Cambridge, have added very remarkably to our knowledge of old sites and new in England and southern Scotland, especially in the area of Roman conquest and military occupation.[57]

In the late 1940's Colonel Baradez analyzed photographs authorized by government authorities in Algeria and with his expert skill in photographic reconnaissance was able to trace the Roman defensive system that they had been trying to uncover in the Sahara for years . Though not taken specifically for archaeological purposes, these photographs made it possible to map the Roman defense systems for several hundred miles. In 1949 he published Fossatum Africa: Aerial Investigations on the Organization of the Borders of the Sahara in the Roman Period.[58]

---

[56] Detweiler, p. 36.

[57] Wheeler, p. 57.

[58] Eydoux, p. 96.

AFTER WORLD WAR II

In the first decade after the war, the fact that archaeological features could be recorded from the air, was still novel. Only in the last decade as the archaeologist has worked in conjunction with soil scientists and geomorphologists, who benefit from mapping dated archaeological sites, has the worth of the archaeologist's findings in photographic interpretation of land forms and vegetation been realized. The study of aerial photography has revealed the manner in which man from his earliest beginning changed his habitat as well as his mode of life.

Before the second World War archaeology belonged to a number of European and American scholars more or less inadequately subsidized and operating in a few selected areas. Except for an occassional spectacular find their discoveries attracted interest mostly only from other scholars. However, since the war, the social and political revolutions sweeping Asia and Africa, have created new nations and new nationalisms. Most of the new or reborn nations, in pride of independence have begun making intensive studies of their own cultural history. Other nations longer established are looking to the backgrounds out of which their national identity emerged.[59]

Aerial photographs help locate ancient settlements which no longer exist, the size of fields and the size of the reservoirs which supplied these fields with floodwater on which they depend exclusively. It is also

---

[59] Froelich Rainey, "The Chaning Face of Archaeology," Expedition, Spring 1960, pp. 14-15.

possible to deduce climate, soil and vegetation conditions as well as the cultivation and soil conservation methods employed by ancient farmers. None of this could have been achieved without aerial photographs.[60] Though more recently archaeology has made frequent use of aerial photographs, their potential for interpreting physio-geographic conditions and the influence of these conditions on man in various historical periods, has not been thoroughly explored.

The Hebrew University, seeking to determine the relation of man to his desert habitat in Israel two thousand years ago, has found indications that in the past a certain area of Israel produced bountifully. The question arose as to whether the climate has changed or whether the methods of irrigation and cultivation have changed. No real headway was made in answering this question, until aerial photography was used. As seen from the ground remains often gave no clues of thier nature or relation to each other; also investigations were fragmentary. Only aerial archaeological techniques made possible generalizing and reaching a definite conclusion about cultivation methods employed by ancient farmers in this arid zone. It was found that lands which had lain outside of human settlement for 1,500 years could be returned to productive cultivation by rebuilding the ancient canals, dams and barriers that had been constructed across the torrential stream beds two thousand years ago. This conclusion could never have been reached without recourse to aerial archaeology which brought out the pattern of half-buried dams and canals. Further studies aimed at planning the renewed exploitation of these areas

---

60 Yehuda Kedar, "The Use of Aerial Photography in Research in Physiogeographic Conditions and Anthropogeographic Data in Various Historic Periods," Photogrammetric Engineering, Vol. 24, No. 4, Sept 1958, p. 584.

for agriculture have been conducted entirely by techniques of aerial archaeology.[61]

Another more recent discovery was made by James Parsons while on a commercial flight approaching the airport at Guayaquil Ecuador. He observed and photographed raised platforms and ridges in the Rio Guayas flood plain. Aerial reconnaissance and photography have established the existence of extensive tracts of ridged fields and planting platforms (bancos) apparently of pre-Columbian origin, in the overflow of lands behind the natural levees of the Rio Guayas immediately north and east of Guayaquil Ecuador. These remains of an ancient labor-intensive agricultural system are similar in character to others that have been described in Bolivia, and Columbia.[62]

The ridged field patterns are so conspicuous from the air yet never seem to have been described in any of the archaeological or geographical literature on the Guayas Basin. It is not surprising that these distinctive man-made features so close to Guayaquil have never been described, because from the ground, they are not easy to detect and go unrecognized by persons not familiar with them. It has remained for aerial photographs to make possible their ready identification and mapping. The field work was supported by the Geography Branch Office of Naval Research.

These ridges have intriguing cultural and ecological implications. The South American fields have a close parallel in the blocks of narrower

---

61 Ibid., pp. 585-587.

62 James J. Parsons, "Ridged Fields in the Rio Guayas Valley, Ecuador," American Antiquity, Vol. 34, No. 1, January 1969, p. 76.

linear "planting beds" described more than a century ago in the upper Mississippi Valley and around the southern end of Lake Michigan and more recently discovered in Macon, Georgia. The possibility of remote, cultural relationships between ancient inhabitants of these distant areas is a fascinating hypothesis.[63]

In the last decade, often called the space age, remote sensing techniques have been revolutionized. Remote sensing "denotes the acquisition of data from the physical environment by means of a data gathering system removed from direct contact with the phenomena investigated."[64] The projects described above were conducted by means of aerial photography, one of the simplest types of remote sensing. Today more complicated devices are used from aircraft and spacecraft; however, remote sensing is not really a new concept, but actually a refinement of the old art of reconnaissance.[65]

Photography is probably the best known remote sensing technique. It has been vastly improved in recent years and from it new sensing devices have been developed. Color photography is coming into much wider use, though it is much more expensive than black and white photography. Many archaeological sites have been recognized by color distinction.[66] A recent study of poorly vegetated semi-arid areas of east-central New Mexico showed color aerial photography to be particularly helpful in problems of geologic interpretation such as: mapping the distribution

---

64 Thomas R. Lyons, "Some Applications of Remote Sensing," University of New Mexico.

65 Ronald J. P. Lyon and Roger S. Vickers, "Remote Sensing: Vision Beyond Sight," Stanford Today, Autumn 1966, p. 2.

66 Lyons, p. 4.

of residual soils; recognition of relic sink holes; and determining the origin of drifting sand present on top of limestone capped mesas. Color aerial photographs almost always contain geological information that is not recorded on conventional black and white aerial photographs.[67]

Multispectral photography provides sets of differential data for the same terrain or geographic area, furnishing much information useful to the archaeologist. Multispectral or multiband photography isolates the reflected electromagnetic energy from a surface in a number of wave length bands, recording each of the spectral bands on film. The differences between materials and objects of interest and the background can be distinguished and studied because various tonal constrasts of terrain result in these photographs. This tonal contrast has been very useful in distinguishing not only various soil types but also geological and cultural features.[68]

In June 1966, the Cambridge Research Laboratory of the United States Air Force did experiments with new multiband aerial cameras on the plain of the Crati in southern Italy. This research was done in collaboration with Dr. Froelich Rainey who has been attempting to locate the archaic Greek site of Sybaris. The new multiband aerial camera was developed by ITEK Corporation as part of a spectral reconnaissance system whose goal is to detect and record surface evidence of underground nuclear explosions.

---

[67] Lyons, pp. 5&6.

[68] William A. Fischer, "Color Aerial Photography in Geological Investigations," Photogrammetric Engineering, Vol. 28, March 1962, p. 134.

The multiband camera contains nine lenses, eight of which record images through eight portions of the spectrum while the nineth records the full spectrum image.[69]

Another type of remote sensing technique records infrared radiation. Near infrared radiation can be recorded on film and intermediate and far infrared radiation are recorded by means of a scanning mechanism or radiometer. A photographic image can be obtained from a radiometric recording, if desired.[70] Remote sensing of infrared radiation is of particular value to archaeological investigations.[71]

In April 1966 thermal infrared scanning images of the eastern part of the San Francisco volcanic field about forty kilometers northeast of Flagstaff Arizona, were recorded with a Reconofax IV (H.R.B. Singer Co.) infrared scanning radiometer. The images revealed the presence of linear features which, subsequent investigations showed, bordered previously unrecognized prehistoric agricultural plots. Shaber and Gumerman have analyzed this area and shown by means of soil and pollen analyses that these linear features are prehistoric agricultural plots. Small habitation sites of four and five rooms were found within several hundred meters of

---

69 "Archaeological Prospecting, Aerial Photography," MASCA Newsletter, Applied Science Center for Archaeology, University of Pennsylvania, Sept. 1966, Vol. 2, No.1, p. 1.

70 Lyons, p. 6.

71 C. W. Ceram, (ed.), "New Methods in Archaeology" Hands on the Past, Alfred A. Knopf, New York, 1966, p. 408.

all the linear features in the area. Thermal infrared images need to be evaluated over different climatic and edaphic zones. Data from the thermal infrared region may usefully supplement conventional aerial photographs (i.e. visible and near infrared) which have already been utilized in archaeological research.[72]

Two other types of recorded data may also prove useful to archaeology. Radar and ultraviolet sensors have successfully been used in acquisition of data in other disciplines. Radar because of its penetration capability, especially is of value in acquiring topographic information in areas of almost constant cloud and fog cover.[73]

Instruments for data collection have been designed for use on both aircraft and spacecraft. A great number of these techniques and interpretative skills have been developed for analysis of space photography and space derived imaged data. The vast potential of these methods of data acquisition and interpretation has only been realized in the past five years or so.

Hyperaltitude and orbital photography has been obtained from space since the first sounding rockets were sent aloft in 1946. However, the full impact of the earth's colorful terrain was not realized till the extraordinary color photographs were returned from the Gemini IV mission in 1965. Previously it had been theorized that satisfactory color photography could not be obtained from orbiting satellites because of the

---

[72] Gerald G. Schaber and Geroge J. Gumerman, "Infrared Scanning Images: An Archeological Application," Science, Vol. 164, May 9, 1969, pp. 712-13.

[73] Lyons, p. 8.

earth's atmospheric light scattering. However, the earth's atmosphere has acted as a translucent sheet in contact with the surface thereby permitting transmittance of a considerable part of the spectrum, and light scattering is strongly dependent upon the wavelength of light being transmitted.[74]

In the Gemini IV mission, orbital color photographs taken over the southwestern part of the United States and African dry areas were more successful than photographs taken over wet areas such as the Gulf coast and the Amazon Delta. A series of overlapping photographs that were taken on June 5, 1965 over the southwestern part of the United States from the mouth of the Colorado River across southern Arizona and New Mexico and adjacent areas of Mexico to the Edwards Plateau of western Texas, offered unique opportunities for determining the extent, correlation and development of some types of soils. Reddish soils were the most conspicuous ones on the photographs and in general are old soils, that developed during intervals of reduced erosion and surficial deposition that were favorable for chemical weathering. The correlation of these soils would be a major factor in correlating Quaternary geologic events in separate drainage basins of the southwest with known interglacial events to the north.[75]

---

[74] Abraham Anson, "Status of Aerial Color Photography in Government Agencies," Geographic Information Systems Branch Geographic Sciences Division, May 1968, p. 45.

[75] Harald Drewes and Roger Morrison, "Extent of Relict Soils Revealed by Gemini IV Photographs," Technical Letter NASA-60, prepared by Geological Survey, October 1966, pp. 1&2.

Harald Drewes and Roger Morrison (1966) have studied the Gemini IV photographs and state that the red soils shown in the vicinity of the Wilcox Playa in Arizona may date as far back as seventy thousand years. Other soils are recognized on these photographs and can be considered evidence in the interpretation of Quaternary geological events in the various drainage basins of the southwestern United States.[76] The synoptic view of broad areas permitted by this method makes it possible to ascertain at a single glance the areas where such soils may be developed at the surface. At the same time it offers the possibility for widespread correlation of soil types in as much as establishing continuity from one basin to another by this means is not subject to the jusual limitations of ground visibility or access.[77] The potential application to "Ancient Man" archaeology of this type of data is broad. Mapped information of the type and age of various soils is an advantage to the research in defining Ancient Man and other problems in selecting potential areas of site occurrences.[78]

The principal problem connected with the analysis of the photographs now available is that insufficient field study has been done to ascertain the following: the age of the soil represented, the influence of source material and degree of development on the resulting images, and the way in which color values as expressed from orbital altitudes are related to those on the ground.[79]

---

[76] Ibid., p. 4.

[77] Ibid., p. 2.

[78] Lyons, pp. 4 & 5.

[79] Drewes and Morrison, p. 2.

In 1968 Jean Pouquet did an analysis of radiometer night time measurements that had been taken by Nimbus I (1964) over the Nile delta area. Using the information from photofacsimilie prints from data gathered over Northern Africa on orbit 258 (September 14, 1964) and orbit 345 (September 20, 1964) of Nimbus I, Pouquet found that the sandy alluvial deposits of the Nile delta when fresh are not able to store enough water; thus, its heat capacity is rather low and its albedo is high. However, alluvium deposited approximately ten thousand to twelve thousand years ago, at the end of the last glacial age, has gone through pedologic evolution, has been weathered and transformed, enriched in clay and organic matter,and its moisture capacity therefore is increased. Pouquet was able to deduce this information from the Nimbus data.[80] This differentiation of pedologic materials by conditions of variable heat flux can be an extremely useful tool to the archaeologist in determining paleoclimate and other aspects of the paleo-environment, together with the probable locations of early human occupants.[81]

Recently (1969) Dr. Yehuda Kedar has been able to utilize photography from the S065 multiband experiment flown on Apollo 9. From the black and white and Ektachrome Infrared photography, Kedar was able to identify ancient Hohokom canals and canal systems in the Phoenix Arizona area. The altitude of the spacecraft at times of exposure varied from 195 to

---

80 Jean Pouquet, "REmote Detection of Terrain Features from Nimbus I High Resolution Infrared Radiometer Nighttime Measurements," NASA Technical Note TN D-4603, Washington, D.C., p. 6.

81 Lyons, p. 7.

127 nautical miles.[82]

Equipment developed for NASA spacecraft is alsc being used to gather archaeological data from balloons and aircraft. The University of Minnesota expedition to Messenia Greece in 1969, used a balloon to fly a wide range of aerial coverage with a variety of black and white color and Infrared flims. The camera used was a Hasselblad El 500, the same as was carried in the Apollo 11 moon flight. The camera was released by short-wave radio and advanced repeatedly from two hundred feet to map the entire area. The same camera and techniques were used at Cosa Italy where the excavations of the Harbor are under the co-direction of Colonel J. D. Lewis of the United States Army and Dr. Anna Marguerite McCann of the University of Missouri in conjunction with the direction of Dr. Frank Brown of the American Academy of Rome.[83]

NASA aircraft is also involved in archaeological studies. During April 9-26, 1969, the NASA 927 aircraft (Lockheed NP3A) flew an Earth Resources Program over sites distributed over a wide area of central Mexico to obtain data for agriculture, geology, forestry, hydrology and oceanography. This was done as the third phase of a program entitled, "Plan for Cooperation between Mexican and U. S. Agencies on Research of Remote Sensing for Earth Survey," a project of NASA and the Comision Nacional del Espacio Exterior of Mexico. The type of information obtained will most

---

[82] Lyons, p. 5.

[83] "Balloon and Airfoil Photography," MASCA Newsletter, Applied Science Center for Archaeology, University of Pennsylvania, November, 1969, pp. 2 and 3.

likely be valuable to Mexican archaeologists. At this time, though a summary report of that mission has been published by NASA, to my knowledge, no publications have appeared explaining the information gained from the photographs nor their possible utilization for archaeological purposes.[84]

At the present time, Professor Gumerman is currently doing archaeological research on archaeological sites in Mexico, utilizing remote sensing imagery in collaboration with the Mexican National Outer Space Commission.[85]

---

84 "Earth Resources Aircraft Program Mission Summary Report - Mission 91," Manned Spacecraft Center, Houston, Texas, June 1969, Introduction.

85 Arch C. Gerlach, Chief Geographer, U. S. Department of Interior, Geological Survey, Washington, D.C. , ltr of August 5, 1970.

CONCLUSION

The space age has started a new era in aerial archaeology. As stated in the introduction, excavation is no longer everything to the archaeologist. Aerial archaeology has given the archaeologist a new perspective, removing him from the various depths of a dig to ever increasing vantage points, so that today important information is gleaned even from space photographs of the earth.

The space age has broadened the archaeologist's horizons. In fact, fantastic as it may sound, many have contemplated the expansion of archaeology to extraterrestrial discoveries. Archaeologists have been confronted with such questions as, "What would you do if a discovery of past civilization was made on Mars?" "Astro-archaeology," the name Schuyler gives to archaeology extended into outerspace, is not as far-fetched as it sounds. "Actual space exploration has been progressing for only eleven years and we have already spread a fair amount of artificial material over the lunar surface. As the exploration of space continues and intensifies a new universe of raw data for the future archaeologist will be created."[86]

However, no matter how convinced of the above prediction one may be, it can not be denied that archaeology has been slow to grasp the potential of modern technology. Aerial archaeology seems to have advanced more by means of serendipity than by any planned program.

---

[86] Robert L. Schuyler, "Archaeology in Outer Space," Space World, Vol. 75, March 1970, p. 13.

Archaeological scholars[87] will frankly state that it is still only recently that their colleagues have begun to realize the potential of aerial techniques of remote sensing. Moreover, they have been even slower to utilize and write about these modern techniques.

Perhaps by the time we have conquered space to the point where "astro-archaeology" is feasible, we will have also utilized the presently available techniques of aerial archaeology to learn more about our terrestrial past.

---

[87] Gerlach, ltr. dtd. Aug. 5, 1970 and Lyons and Gumerman, excerpt from a forthcoming paper.

BIBLIOGRAPHY

Ackerman, James S. and Carpenter, Rhys, Art and Archaeology, Prentice-Hall, Inc., New Jersey, 1963, pp. 22-29.

Agache, R., "Aerial Reconnaissance in Picardy," Antiquity, Vol. 28, 1954, pp. 113-118.

Anson, Abraham, "Status of Aerial Color Photography in Government Agencies," Geographic Information Systems Branch G ographic Sciences Division, May 1968, p. 45.

"Archaeological Prospecting, Aerial Photography," MASCA Newsletter, Applied Science Center for Archaeology, University of Pennsylvania, Sept. 1966, Vol. 2, No.1, p. 1.

"Balloon and Airfoil Photography, " MASCA Newsletter, Applied Science Center for Archaeology, University of Pennsylvania, November, 1969, Vol. 5, No. 2., pp. 2-3.

Bradford, John, Ancient Landscapes: Studies in Field Archaeology, G. Bell and Sons, Ltd., London, 1957, pp. 1-87.

Ceram, C. W., (ed.), Hands on the Past, Alfred A. Knopf, New York, 1966, pp. 388-408.

Cottrell, Leonard, (ed.), The Concise Encyclopedia of Archaeology, Hawthorne Books, Inc. New York, 1960, pp. 71, and pp. 315-318.

Crawford, O. G. S. and Keiller, Wessex From the Air, Oxford University Press, London, 1928, pp. 1-12.

Daniel, Glyn E., A Hundred Years of Archaeology, Gerald Duckworth and Company, Ltd. London, 1950, pp.294-300.

Daniel, Glyn E., Man Discovers His Past, Thomas Y. Crowell Company, 1968 pp. 76-78.

Detweiler, Henry A., Manual of Archaeological Surveying, American Schools of Oriental Research, New Haven, 1948, pp.35-39

Deuel, Leo, Flights into Yesterday, The STory of Aerial Archaeology, St. Martin's, New York, 1969.

Drewes, Harald, and Morrison, Roger, "Extent of Relict Soils REvealed by Gemini IV Photographs," Technical Letter NASA-60, prepared by Geological Survey, October 1966, pp. 1-4.

Eydoux, Henri-Paul, History of Archaeological Discoveries, Leisure Arts, Ltd., Switzerland, 1966, p.96.

"Earth Resources Aircraft Program Mission Summary Report- Mission91," Manned Spacecraft Center, Houston, Texas, June 1969, Introduction.

Fischer, William A., "Color Aerial PHotography in Geological Investigations," PHotogrammetric Engineering, Vol. 28, March 1962, pp.134-139.

Gerlach, ARch C., Chief Geographer, U. S. Department of Interior, Geological Survey, Washington, D.C., ltr of August 5, 1970.

Gillie, Darsie, "Location of Archaeological Sites by Air," The Explorers Journal, Vol. 34, No. 2,3,4, 1956, pp.15-17.

Gorenstein, Shirley, Introduction to Archaeology, Basic Books, Inc., New York, 1965, pp. 42-44.

Grimes, W. F., (ed.), Aspects of Archaeology in Britain and Beyond, H. W. Edward Pub., London, 1951, pp. 300-315.

Kedar, Yehuda, "The Use of Aerial Photography in Research in Physiogeographic Conditions and Anthropogeographic Data in Various Historic Periods," Photogrammetric Engineering, Vol. 24, No. 4, Sept. 1958, pp. 584-587.

Kernan, Michael, "An 'Overview' of Aerial Photography," Washington Post March 30, 1970.

Lyon, Ronald J. P., and Vickers, Roger S., "Remote Sensing: Vision Beyond Sight," Stanford Today, Autumn 1966, pp.2-6.

Lyons, Thomas R., "Some Applications of Remote Sensing," University of New Mexico. pp. 1-10.

Lyons and Gumerman, excerpt from a forthcoming paper.

Manual of Photographic Interpretation, American Society of Photogrammetry, Washington, D.C., 1960, pp. 717-732.

Miller, William C., "Uses of Aerial Photographs in Archaeological Field Work," American Antiquity, Vol. 23, No. 1, pp.46-62

Parsons, James J., "Ridged Fields in the Rio Guayas Valley, Ecuador," American Antiquity, Vol. 34, No. 1, January 1969, pp.76-80

Pouquet, Jean, "Remote Detection of Terrain Features from Nimbus I High Resolution Infrared Radiometer Nighttime Measurements," NASA Technical Note TN D-4603, Washington, D.C., pp. 1-7.

Rainey, Froelich, "The Changing Face of Archaeology," Expedition, Spring 1960, pp. 14-20.

Reeves, Dache M. , "Aerial Photography and Archaeology," American Antiquity, Vol. 2, pp.102-107.

Schaber, Gerald G., and Gumerman, George J., "Infrared Scanning Images: An Archeological Application," Science, Vol. 164, May 9, 1969, pp. 712-13.

Schuyler, Robert L., "Archaeology in Outer Space," Space World, Vol. 75, March 1970, p. 13.

Simmons, Harold C., Archaeological Photography, New York University Press, 1969, pp. 1-2 and 84-94.

Smith, John T., Jr., (ed.), Manual of Color Aerial Photography, American Society of Photogrammetry, 1968, pp. 385-386.

St. Joseph, J. K. S., "Air Photography and Archaeology," Geographical Journal, Vol. CV, Jan.-June 1945, pp.47-61.

St. Joseph, J. K. S., The Uses of Air Photography, John Baker Pub., Ltd., London, 1966, pp. 26-31 and 113-125.

Wheeler, "New Techniques," S. Rapport & H. Wright (ed.), New York Univ. Press, 1963, pp. 55-57.

Winchester, Clarence and Willis, F. L., Aerial Photography, A Comprehensive Survey of its Practice and Development, Chapman & Hall, Ltd., 1928, pp.170-176.